

Missouri River Updated Stage-Frequency Below Gavins Point Dam

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Abstract

Revised stage-frequency profiles for the Missouri River were developed from Gavins Point Dam downstream to Rulo, Nebraska, using the updated flow-frequency values. Period of record inflow hydrographs were routed with a current condition unsteady flow model to determine a stage-discharge relationship at each cross section using the annual maximum values. A statistical analysis combines the flow-frequency with stage-discharge to determine stage-frequency values at each individual cross section. Analysis methods and model development issues including ungaged inflow, calibration, and stage-trends are discussed. Sensitivity analysis was performed using the period of record model to assess the impact of model parameters on computed stage-frequency results. Parameters that were evaluated include calibration, levee overtopping, model inflow, and period of record length. The application of stage-frequency to address environmental issues including flooded area to define habitat is discussed.

Missouri River Description

The Omaha District performed hydraulic modeling to determine stage-frequency on the Missouri River. The hydraulic model extends from Gavins Point Dam, at river mile (RM) 811.1, downstream to Rulo, NE, at RM 498.0. Rulo, NE, corresponds with the Omaha District boundary with the Kansas City District. The Omaha District hydraulic model includes 313 miles of the Missouri River and 211 miles of tributaries. Within the model limits, the Missouri River drainage area increases from 279,500 square miles at Gavins Point Dam to 414,900 square miles at Rulo. In order to provide an accurate downstream boundary, the hydraulic model also includes geometry between Rulo, NE and St. Joseph, MO. This adds an additional Missouri River length of 49.9 miles to the hydraulic model.

Reservoirs. The most significant flood control projects constructed within the basin are the six main stem Missouri River Dams. The six dams, which were completed by 1964, provide flood protection by controlling runoff from the upper most 279,000 square miles of the drainage basin. The reservoir system has a total combined capacity in excess of 73 million acre-feet of which more than 16 million acre-feet is for flood control. Gavins Point Dam, located near Yankton, SD at river mile 811.1, forms Lewis and Clark Lake and is the most downstream of the projects. Hydraulic modeling begins downstream of Gavins Point Dam.

Navigation. There were seven acts of Congress that provided for the construction,

operation and maintenance of a navigation channel and bank stabilization works on the Missouri River. The most recent was authorized in 1945 and provided for bank stabilization combined with a 9-foot deep and not less than 300 feet wide navigation channel. The authorized project for the Missouri River extends from its confluence with the Mississippi River at St Louis, MO to Sioux City, IA for a total distance of 734.2 river miles.

Levees. The Missouri River levee system was authorized by the Flood Control Acts of 1941 and 1944 to provide protection to agricultural lands and communities along the Missouri River from Sioux City, IA to the mouth at St. Louis, MO. The levees were designed to operate in accord with the six main stem dams. The extent of the levee system within the Omaha District consists of levee units on both banks from near Omaha, NE to near Rulo, NE or a distance of about 120 river miles. The levee system provides varying levels of protection (USACE, 1986).

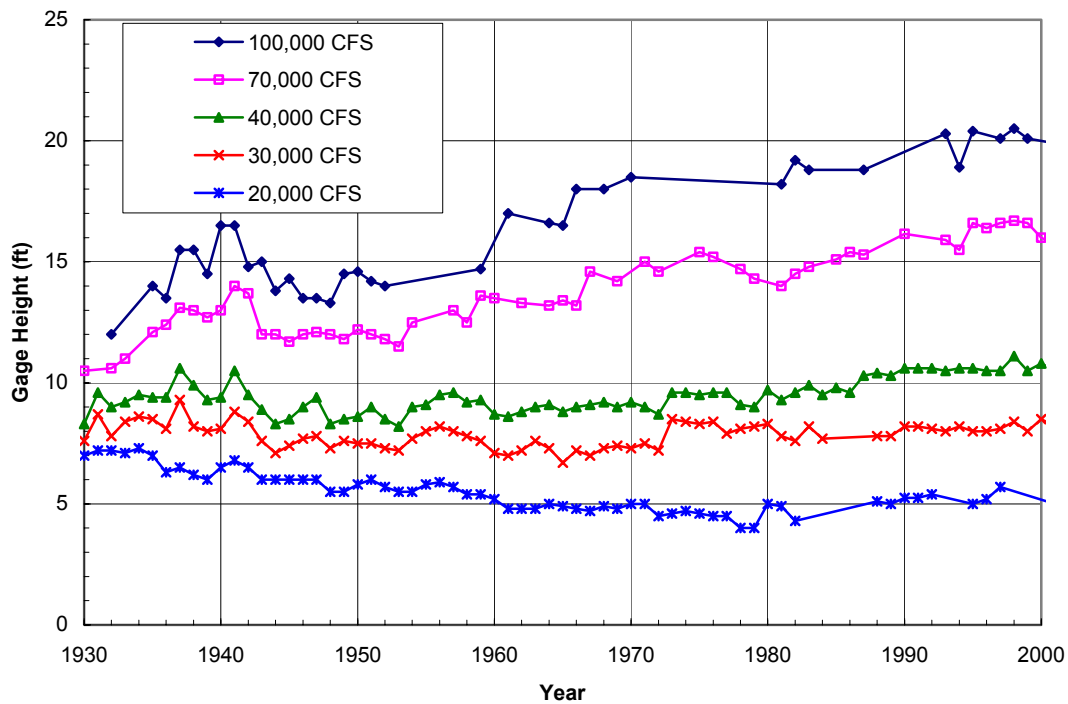
Stage Trends. Over the last 100 years, significant change has occurred in channel conveyance as a result of aggradation and degradation. Missouri River natural variability and construction including flood control projects, channel cutoffs, channel and bank stability projects have all contributed to conveyance change. Numerous studies have been conducted by the Omaha District to quantify the impact of Missouri River geometry changes on the stage-flow relationship (USACE, 2001, 1981). Data collected at Missouri River gaging stations demonstrates shifts in the stage-discharge relationship. The shift of the rating curve varies according to location with degradation in the upper reach and aggradation in the lower reach. An example of the stage trend at the Nebraska City USGS gaging station location is shown in figure 1.

UNET Model

An unsteady flow model of the Missouri River was constructed by the Omaha District. UNET was employed as the unsteady flow model for the basin wide modeling tool. UNET is a one-dimensional unsteady flow program that includes the capability of simulating a complex network of open channels. Unsteady flow routing accounts for the variation in flow with both time and space. The UNET model has the ability to account for critical backwater effects in the routing and can directly simulate flows that spill over or breach a levee. The UNET model utilized for computational purposes includes customized options developed via contract with Dr. Robert L. Barkau and is referred to as version 4.0, LAN version 1.0, executable date 9/12/2002.

The geometry input file consists of the HEC-2 style cross sectional geometry developed by the user. Cross section data for the Missouri River was extracted from digital models developed from floodplain and hydrographic survey data. Missouri River cross section spacing was approximately 2000 feet. Cross section location was limited to the location of hydrographic survey data.

Figure 1. Nebraska City Specific Gage Analysis.



Many steady flow analysis models require construction of separate models for different frequency events making it possible to vary the effective flow area within a cross section for different flow rates. The UNET model employs a single geometry for the entire period of record. Within the UNET model, bank stations and effective flow areas are specified at each cross section. The model included an encroachment at the bank station to confine all flow to the channel until the bank station is exceeded. An additional station was specified within the section to define ineffective flow within the model after the channel capacity is exceeded. Since the model was constructed to model a full range of flows, placement of a single encroachment station within the floodplain was usually based on higher flows. An analysis of active top width at a specific flow determined that some inconsistencies occur. The single geometry for the cross section is a limitation of the UNET model.

Most cross sections within the model employed horizontal roughness variation to specify Manning n values. Roughness values were coded for the main channel, sand bars and light vegetation, farming areas, and trees or heavy vegetation. Cross section geometry was included within the UNET model for all major tributaries for the reach from the confluence with the Missouri River upstream to the USGS gaging station location.

Flow and stage hydrographs for the Missouri River and tributaries are required for all boundary conditions and lateral inflow points. Daily hydrographs were employed for all UNET analysis. Historic hydrologic data was obtained from the USGS' Automated Data Processing System (ADAPS) which is part of the National Water Information System (NWIS). The model employs in excess of 30 inflow hydrographs for tributary and lateral inflows.

Federal Levees. Areas to the landward side of the federal levees were included

within the UNET model by describing each area with a stage-storage relationship. Levee overtopping or breaching will affect model timing and computed results if a significant amount of flow is conveyed into the levee cells. A levee interior acts as a storage cell, which interacts with the river through a breach or breaches in the embankment, until the interior area is filled to overflowing. At this point the area behind the levee no longer acts as a storage cell, but begins to actively convey flow. For extreme floods, the entire floodplain, bluff to bluff, begins to convey flow and the levee cell is directly connected to the main river with a similar water surface elevation. UNET can simulate levee systems with a variety of methods. Within the Omaha District, levee cells were described with a stage-storage relationship. The levee cell is connected to the mainstem Missouri River within the UNET model and adjacent levee cells. Connections were established within the UNET model at the upstream and downstream limits of each levee cell. Levee modeling assumptions were coordinated during task force meetings with Corps of Engineers, FEMA, and state representatives.

Calibration. Calibration of the UNET model was an iterative process performed in several stages. Calibration efforts focused on reproducing observed stage hydrographs at gaging stations along the Missouri River and verifying with discharge measurements. Calibration of an unsteady flow model is an iterative process. Significant changes to model geometry will also affect routed flow. The calibration process strives to maintain both flow and stage accuracy. Initial model calibration consisted of setting Manning roughness values for each cross section. The calibration was refined by adjusting the model rating curves (KR records). The conveyance change and discharge conveyance relationship were used in conjunction with the rating curves to finalize the model calibration. Therefore, final calibration is a combination of the effects of all the parameters employed in both the geometry and boundary condition files. A description of the model calibration steps is as follows:

Base Roughness. The base Mannings' roughness values were calibrated to recent measured steady water surface profiles. All measured profiles were for within channel flows in the normal operating flow range during the navigation season.

Ungaged Inflow. The model evaluates ungaged inflow using the Null Internal Boundary Condition (NIBC). The NIBC feature is used by the Omaha District to reproduce flow at the USGS gage locations at Sioux City, Decatur, Omaha, Nebraska City, and Rulo. Use of the NIBC is an important component of calibrating the model to both flow and stage. The technique optimizes ungaged inflow to reproduce the observed flow hydrograph at the NIBC station. Optimizing flow is used to maintain the observed flow record for the period of record analysis. Due to the computation procedure, the computed ungaged inflow compensates for all the errors in the tributary inflow data set, the measurement of stage and flow, and for systematic changes in roughness and geometry that may not be included in the model. As a result, the ungaged inflow determined using the NIBC procedure includes both ungaged inflow and a lumped error correction term to correct model flow.

Automated Calibration. Once the model is nearly calibrated, the automated calibration is performed by pairing observed stages at the stream gages on the Missouri River with routed flow. Using a KR record in the UNET geometry file at each stream gage location applies this relationship to the ordinates in the cross section tables. The KR DSS file record is modified during the calibration process to increase accuracy. Calibrated KR records were employed at all Missouri River gaging stations.

Final Calibration. The UNET program has three tools for fine-tuning the model that are applied within the boundary condition file. The different methods all affect the discharge-stage-conveyance relationship at a cross section within the model. Final calibration was performed using seasonal correction, conveyance change, and discharge-conveyance relationships for separate reaches within the model.

Several different events were employed for calibration. Calibration events are limited due to the conveyance impacts that have occurred on the Missouri River. Previous studies, discharge measurements, and observed data all demonstrate that the Missouri River stage-discharge relationship has seasonal and annual fluctuations (USACE, 1976, 2001). Calibration methods focused on selecting a single best fit relationship for the entire model reach. An example of model calibration is shown in figure 2.

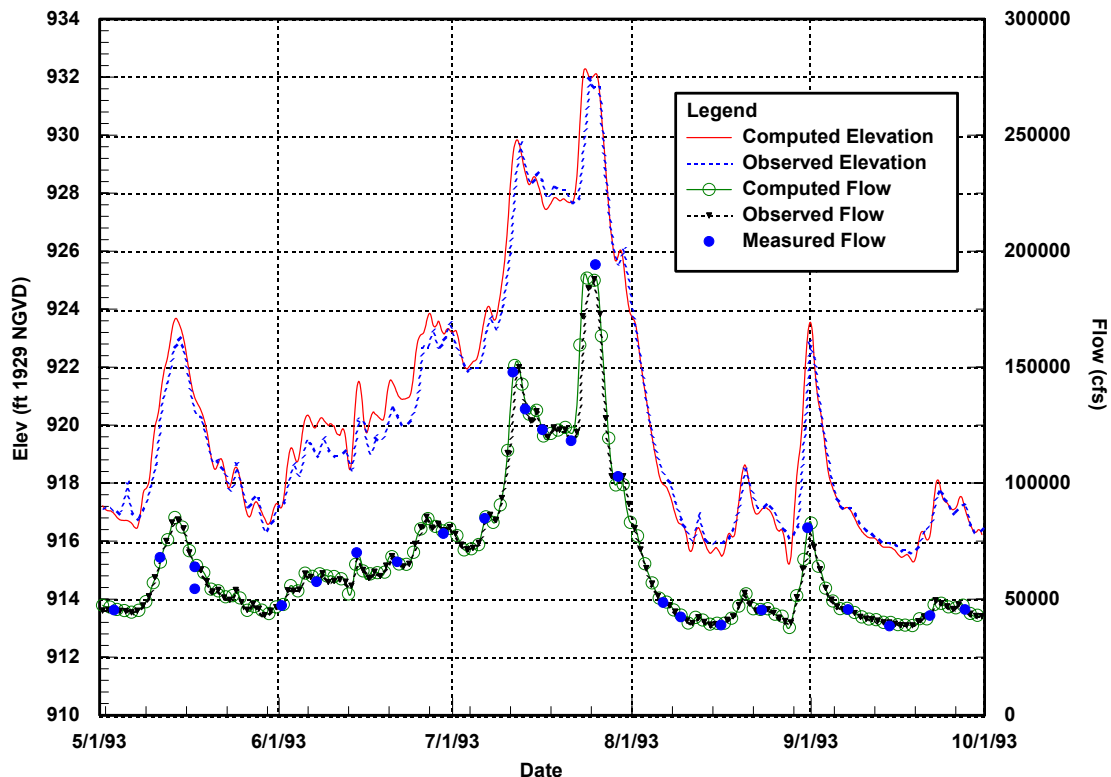


Figure 2. Missouri River at Nebraska City, 1993 Event.
Period of Record Analysis

The calibrated UNET model was used to perform a period of record (POR) analysis. The period of record analysis refers model simulation using 100 years of flow data for the time period from 1900 to 2000. The period of record analysis includes a substantial amount of simulated data. The ungaged inflow procedure was used to estimate tributary inflow for periods prior to establishment of the gaging station. While significant geometry and conveyance changes have occurred in the past 100 years, the POR analysis uses the historical flow record, not the stage record. Since the model is calibrated to the current condition, the period of record analysis computes stages that would occur if the historical record were repeated. The POR analysis is performed with the calibrated UNET model. The analysis uses daily flow data for all inflow hydrographs with a 3 hour computational time step.

During the POR analysis, the model will activate either or both levee connection if the computed water surface elevation exceeds the coded levee top elevation. Levee connections are repaired when the river stage drops below the coded elevation. When both the upstream and downstream connections are active, the levee cell conveys flow parallel to the main river.

The purpose of the POR analysis is to generate 100 years of stage-flow data at all UNET model cross section locations by simulating the observed flows. Annual maximum flows and stages are collected using the Annual Maximum flag within the UNET boundary condition file. In order to correctly account for total flow at a cross section, the flow within the levee cell must be included in the total flow. The total flow is determined by using the Parallel Flow flag within the UNET boundary condition file.

Stage-Frequency Analysis

Using the output from the UNET POR analysis, stage-frequency relationships may be determined at all UNET model cross section locations. The POR analysis does not generate a traditional 100-year profile. Several additional steps are required using software analysis programs developed by the Hydrologic Engineering Center (HEC). The steps involved are summarized as follows:

- a. Run the UNET POR model.
- b. Extract the annual maximum flow and stage.
- c. Fit a spline curve through the stage-flow relationship at each cross section.
- d. Interpolate the flow-frequency between the gage stations to each cross section using drainage area.
- e. For the flow-frequency value at each cross section, determine the corresponding stage from the stage-flow relationship.
- f. Develop the final profile after corrections for backwater areas and profile smoothing.

The UNET period-of-record simulation creates a DSS file containing the annual maximum discharge and annual maximum stage information for each year from 1900

through 2000. The suite of HEC developed software programs were then used to process this annual maximum data to produce the discharge and stage profiles. From the POR annual maximum file, the HEC software determines a best-fit spline curve of the paired, ranked data. While the spline curve is typically referred to as a rating curve, it is, in essence, a curve relating the discharge and stage frequencies. A spline curve was selected as the technique to fit a curve through the computed stage-flow points to form a rating curve at each cross section. The rating curve can be very non-linear, reflecting changes in channel cross section geometry.

During the hydrologic analysis, a regulated flow-frequency relationship was determined at each cross section. The drainage area was specified at each cross section. A second HEC program uses the unregulated gage statistics, the regulated-unregulated relationship, and the drainage area at each cross section to interpolate at all locations the regulated flow-frequency. Using the developed spline curve and the flow-frequency relationship, the HEC software then computes a stage-frequency relationship at each cross section. By combining the results at all cross sections, the profile for a single event, such as the 100-year, may be developed.

Final Profile Development

The final step in determination of the stage-frequency relationship is to import the data from the HEC suite of programs into the profile plotting spreadsheet. The final output file from the HEC program contains tabulated flow-frequency and stage-frequency for each cross section. Initial results exhibited some areas where the profile had dips or inconsistencies. These variations were most pronounced for the 500-year event and the 100-year event to a lesser extent. Given that the methodology employed a single geometry file for the entire analysis, some inconsistencies are not unexpected. For large events, top width and flow velocity variation contributes to excessive stage variation between adjacent sections.

A simple profile smoothing algorithm was applied to the final results within a spreadsheet prior to plotting. The output results were also modified in the vicinity of the major tributaries. Upstream of tributary junctions, results were compared with an HEC-RAS generated backwater profile to evaluate the profile slope. The combined results from the stage-frequency software, the smoothing algorithm, and the backwater analysis were used to determine the final profiles. Water surface profiles were developed for the 10-year, 50-year, 100-year, and 500-year flood events. An example profile is illustrated in figure 3.

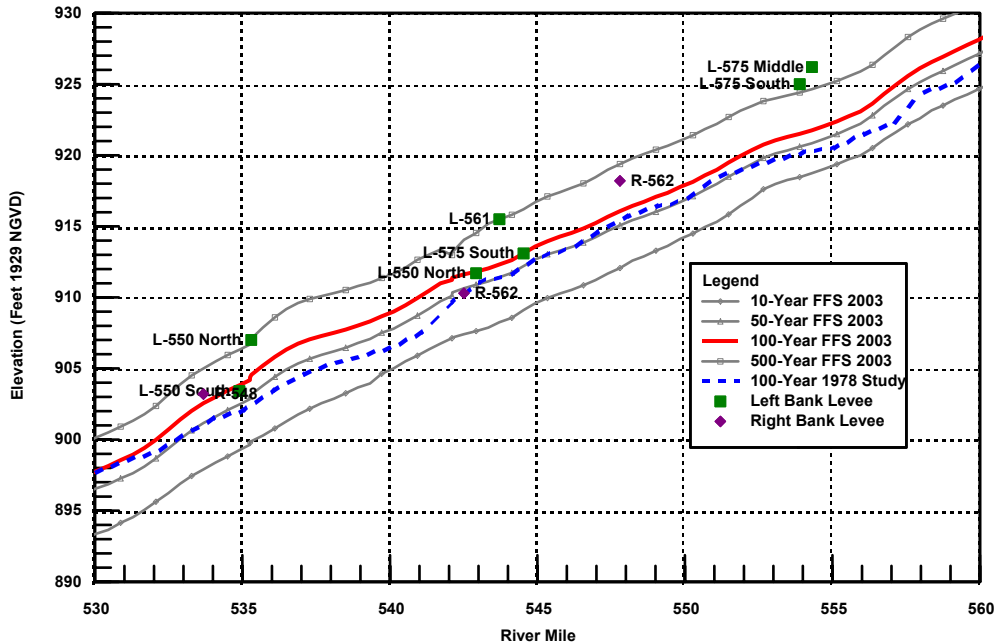


Figure 3. Example Profile Plot.

Sensitivity Analysis

Sensitivity analysis was performed with the UNET model to evaluate the impact on computed profiles. Sensitivity analysis looked at several parameters including river conveyance increase, river conveyance reduction, levee confinement with no federal levee failure, fast levee connection that increased conveyance through the levee cell, simulating without any ungaged inflow, and factor flows for a portion of the period of record length. The parameters were designed to evaluate model sensitivity to parameters such as model calibration, model conveyance, period of record length, and flow volume. Analysis compared results to the base calibrated model. Comparison between results was performed at selected locations and also for specific reaches. The results of the sensitivity analysis were used to verify model performance and develop stage error estimates for the risk analysis.

Sensitivity was performed by river mile (RM) for the entire model. Analysis compared results for the alternative condition to the base condition. An example plot of sensitivity analysis results is shown in figure 4. Figure 4 illustrates changes for the 100-year event only. Analysis was also performed for the 10-, 50-, and 500-year events. The sensitivity analysis results demonstrated that the model performs reasonably in that parameter changes generate expected results.

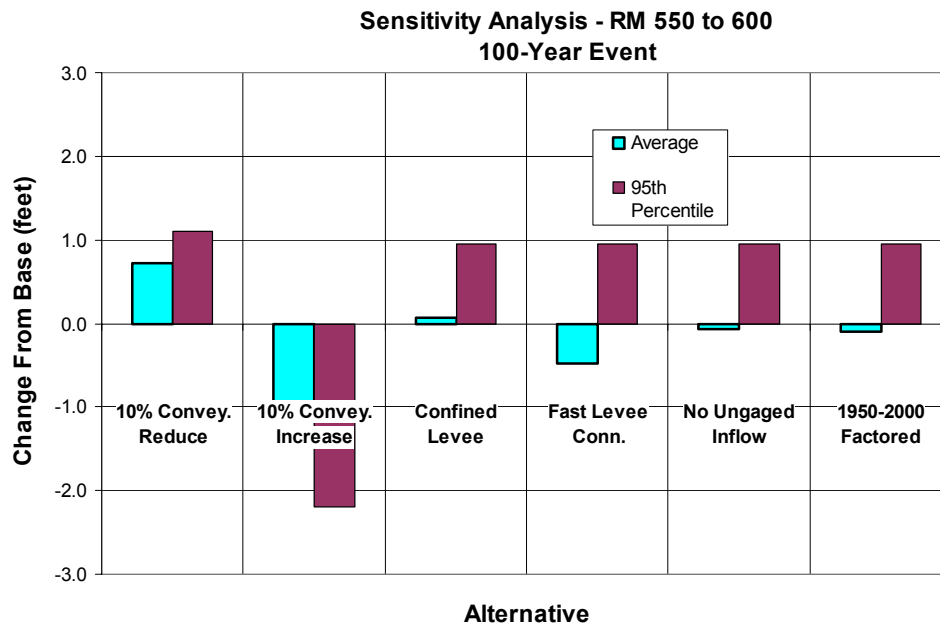


Figure 4. Sensitivity Analysis Example.

Conclusion

The Omaha District performed hydraulic modeling along the Missouri River for the purpose of determining stage-frequency. The hydraulic model extends from Gavins Point Dam, at RM 811.1, downstream to Rulo, NE, at RM 498.0. Rulo, NE, corresponds with the Omaha District boundary with Kansas City District.

The UNET model developed for this study employed the top of levee elevation for all levee connections. The model also assumes a levee breach occurs when the computed river elevation exceeds the levee top elevation. Previous Missouri River studies within the Omaha District conducted to develop regulatory products such as the stage-frequency elevation and 100-year floodway used different assumptions and a steady state hydraulic model to determine stage profiles.

A UNET period of record analysis was employed to develop a data set of annual maximum flow and stage at all cross sections. Software was employed to determine stage-frequency relationship at all cross sections using hydrologic data, regulated-unregulated relationships, and UNET results. Profile smoothing and adjustment to the profile through backwater areas was also required. A sensitivity analysis was performed to evaluate the impact of model parameters on computed results. Final profiles for the study reach were developed that include a comparison to the previous study results.

- Final profiles for the 10-, 50-, 100- and 500-year events were determined from Gavins Point Dam (RM 811.1) to Rulo, NE (RM 498).

- Significant changes to the flow-frequency relationship have occurred since the previous flood hazard study (USACE, 1978). The most notable changes are the 500-year event downstream of the Platte River and all events upstream of Sioux City.
- Calibration accuracy was limited by the dynamic stage-flow relationship on the Missouri River. Degradation within the upper end of the model and aggradation in the lower end has significantly impacted the stage-flow relationship.
- Calibration efforts focused on current conditions. Future stage trends are not included within the analysis.
- The UNET period of record analysis employed a single calibrated model to best fit current conditions. Missouri River stage-discharge relationship has seasonal and annual fluctuations. Model calibration error is known to occur for each individual event. Final calibration represents the model determined to be best suited for the POR analysis.
- The POR analysis employed a model calibrated to summer stages. The impact of seasonal stage-flow was minimized in order to reduce model variability and prevent computation of lower stages for spring or fall events in the POR analysis.
- All model calibration and the POR analysis was performed with daily flow data. While calibration accuracy may be reduced, the computed results, which rely on the developed stage-flow relationships, are still valid.
- A sensitivity analysis was performed to evaluate the impact of model parameters such as model calibration method, ungaged inflow, levee overtopping and conveyance, the period of record length, and flow factoring. Results indicated that the model performed adequately.

Reference

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